ON THE CORRELATION OF SEISMIC SCALES

- USSR -

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FOREWORD

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Summary

This article describes the historical background of the problem
concerned with the drawing of seismic scales and gives a table showing
a comparison of various scales.

At the present time, approximately 50 different seismic scales,
i.e. scales used in determining the force of an earthquake, have been
published in various countries. Without delving into problems con-
cerned with the nature of the concept "seismic intensity division"
(seismicheskiy ball), we would like to give a very general description
of the most important scales and to attempt a correlation of these
scales. This is necessary in view of practical problems encountered
during the study of seismic conditions in various territories, aimed
at establishing specific laws governing seismic phenomena, and also as
a result of problems associated with further research in the field of
seismic regional occurrence on the territory of the USSR.

1. Early Attempts in Drawing Up Seismic Scales

The first attempt to classify underground tremors according to
their intensity and also to draw up a seismic chart was apparently
made by J. Gastaldi, a Piedmont cartographer, in 1564. J. Gastaldi
was attempting to show on his chart the external effect produced by
an earthquake which occurred in Nice on 20 July 1564 (/85/, p. 98).
Further, information is also available on similar work performed
by the Italian Poardi, who divided underground tremors according to
their intensity into 4 stages, and applied his scale to the study of
an earthquake which occurred in Apulia on 30 July 1627 (70, 85, p. 98).
The next study of a similar nature was conducted in 1783. In
the spring of 1783, an extremely violent earthquake occurred in Calabria,
which resulted in a large number of human casualties (ranging from
20,000 to 100,000 people, according to various sources), and which
covered an area of up to 300,000 sq. km in size. According to the
scale presently adopted in the USSR (5), the intensity of underground

tremors in the epicenter amounted to 10-12. This earthquake is known
under the name of the Great Calabrian quake and has been the subject
of a large number of special studies such as, specifically, the study
performed by G. Vivensio (27, 89). In this study, it is stated that
the physicist D. Pignatoro (1735-1802), working at the Monteleone
observatory, together with Sarconi, studied in detail the aftereffects
of the earthquake, and on this basis, worked out a 5-division intensity
scale for identifying underground tremors according to their intensity,
and also drew up a chart. This scale included almost the entire range
of tremor intensities covered by the present scale, namely tremors with
an intensity ranging from 2 to 12. During the year 1783, a total of
948 underground tremors were recorded in Calabria, of which, according
to D. Pignatoro's classification, 501 were very weak, 235 were medium,
175 were strong, 32 were very strong, and 5 were exceptionally strong.

Further, already in the 19th century, come, in chronological
order, the scales worked out by D. Brooks in 1811 (20), P. Egen in 1828
(30), P. Macfarlan in 1839 (58), A. Peterman in 1856 (90), R. Mallet
in 1858 and 1862 (47, 48), R. Williamson in 1870 (94) and Z. Maso in
1870 (50). Certain data pertaining to these scales are listed in the
well-known monograph published by F. Montessus de Ballore (61), and
also in the articles of C. Davison (26-28) and V. A. Bykhovskiy (1).
The reason why we mention these scales is that they were in use prior
to the scale of Rossi-Forel, which became widely known at a later date.

D. Brooks lived in Louisville, near the town of New Madrid in
the USA, and systematically recorded underground tremors associated
with the catastrophic quake which occurred in New Madrid between 16
December 1811 and 7 February 1812. D. Brooks divided the tremors,
according to the effect which they produced, into 6 grades ranging from
the most violent tremors, resulting in the destruction of cities, to
hardly noticeable tremors (20, 26).

P. Egen (1793-1849), a teacher of mathematics and physics in the
town of Elbarfeld, worked out his own 6-division intensity scale in
connection with the Netherland (Rhine) earthquake of 23 February 1828.
The designation of the divisions followed a reverse sequence, as com-
pared to D. Brooks' scale. Particular attention was devoted by P. Egen
to weak tremors, since strong earthquakes do not occur on the territory
of lowland European countries. P. Egen drew a chart of the Netherland
quake showing the tremor intensity at each point, but did not plot
isoseisms (isoseismic lines). Having established the location of the
epicenter with the aid of this chart, P. Egen refuted the statement
claiming that this particular earthquake was allegedly associated in
some manner with an eruption of Mt. Vesuvius (26, 30, 61, 85).

An increased activity of the well-known seismic center in Comrie,
Pertshire, Great Britain was noted in the fall of 1839. A tremor of
the greatest intensity was noted on 23 October 1939 (equal to 7 divisions
according to the present scale), after which repeated tremors were ob-
served during the course of a number of years. P. Macfarlan, a postal

employee in Comrie, systematically recorded these tremors and identified them with the aid of a 10-division scale, which included all intensity rates, from hardly noticeable tremors to tremors of the same intensity as the one which occurred on 23 October 1839 (26, 58, 73).

The first isoseism chart was apparently plotted by the Hungarian botanist P. Kitaybel and the physicist A. Tomtsani, who, while studying the earthquake of 14 January 1810 in Mor (Hungary), plotted the contours of the area in which tremors of the greatest intensity had occurred, actually utilizing for this purpose the concept of isoseisms (according to A. Rethly /75/, p. 231). Forty-two years later, a new isoseism chart was plotted by A. Peterman (1732-1878), who drew this chart in color for the report submitted by O. Folger on the earthquake of 25 July 1855 in the Visp valley (Switzerland). In drawing his chart, A. Peterman used a 5-division scale, which did not include the indices corresponding to divisions 1 and 2 of the present scale.

More widely accepted were the studies performed by R. Mallet (1810-1881). This scientist utilized two types of seismic scales in his investigations, namely a 3-division and a 5-division scale. The first one (1858) was used by the author in drawing the well-known seismic world charts. In this connection, earthquakes were divided into 3 categories: weak, medium and strong. The second scale (1862) was concerned mainly with strong tremors, lying above 7 divisions (according to the present scale), and was used in studying the destructive earthquake which occurred in Naples on 15 December 1857 (26, 29, 47, 48).

G. Wood, in his article describing the destructive earthquake of 1868 in the Hawaiian Islands, gives a list of underground tremors compiled by R. Williamson. The latter divided the tremors, according to their intensity, into 6 grades, designating the latter with the initial letters of the corresponding adjectives: vl (very light tremors), l (light tremors), etc. (26, 94).

The scale devised by Z. Maso also included 6 grades and was adapted to the study of earthquakes occurring in sparsely populated and low-developed countries, in which it is not possible to conduct observations of normal buildings. Since 1870, this scale was used in studying earthquakes on the Philippine Islands (26, 50).

2. Formation of the 12-Division "International" Mercalli-Cancani-Sieberg Intensity Scale

M. Rossi's Scale of 1874 (80, 81). The scales mentioned above did not find a wide field of application, but to a certain extent prepared the ground for the establishment of more modern scales. These include first of all a scale developed by Professor M. S. Rossi (1834-1898), a well-known Italian seismologist and director of the Geodynamical Observatory in Rocca di Papa, near Rome. M. Rossi was the founder of the journal "Bulletino del Vulcanismo Italiano," and published a

list of Italian earthquakes during 1873 in the first volume of this journal. In order to divide the earthquakes given in this list according to their intensity, M. Rossi drew up a 10-division scale, which was printed in an abbreviated form in the first volume of the journal (Anno 1, 1874, p. I), and in an expanded form in the second volume (81 p. III) and in the third volume (80 p. I). Later, M. Rossi again described his scale (see above reference Anno 4, 1877, pp. 39-40; Anno 5, 1878, p. 46). M. Rossi's scale was successfully used during research studies conducted in many countries, for example during the study of the strong earthquakes of 1886 in Charleston, of 1896 in Hereford, etc.

F. Forel's Scale of 1881 (31, 32). In 1878, the Swiss Natural Science Society set up a commission, which was entrusted with a study of earthquakes occurring in Switzerland. An active participant in the work of this commission was F. Forel (1841-1912), a well-known Swiss seismologist and professor at Lausanne University. In particular, he proposed the use of a new scale also consisting of 10 divisions, like M. Rossi's scale, for studying earthquakes. The proposal made by F. Forel was immediately adopted and utilized by M. A. Heim, who studied Swiss earthquakes, and later by R. Hernes in his basic monograph on earthquakes, etc.

Heim's-Forster's Scale of 1882 (40). In 1882, M. Heim and V. Forster, in agreement with F. Forel, modified somewhat the latter's scale, by breaking up division 4 into several divisions, in order to enable a more convenient use of the scale during the study of low-intensity earthquakes (40). Later, a number of additions to the scale obtained in this manner were suggested by R. Leonard and W. Volz (45), and also by F. Suess in his carefully written book describing the Leybach earthquake of 14 April 1895 (87, p. 453).

The Rossi-Forel Scale of 1883 (26, 31, 79). F. Forel, while working on his scale, did not know about the existence of M. Rossi's scale, although both of those scales were very closely related. "In view of the obvious priority rights enjoyed by Mr. Rossi," wrote Forel, "I would have immediately abandoned the scale which I had devised, if I had not received a proposal from M. Rossi and Gatt to revise these scales together, taking our past experience into consideration. I readily accepted this proposal, but work involving a revision of these scales will require a rather long time, and we shall be able to complete this work only next year" (/32/, p. 466). Shortly thereafter, M. Rossi and F. Forel met and combined their respective scales, thus establishing a new scale known since that time as the Rossi-Forel scale (see Appendix 1). Since 1883, this scale has been used in a number of countries, such as Italy, Switzerland, etc., and also in Russia.

The Rossi-Forel scale is the one which is the most widely used, in comparison to all other scales, and is even occasionally encountered in modern investigations.

Somewhat later, in 1888, E. Holden (1840-1914), director of the Leaks Observatory, attempted to correlate the subdivisions of the Rossi-Forel scale with the values of maximum seismic accelerations derived from data obtained in an analysis of a large number of Californian earthquakes investigated by him. This study, which in its theoretical aspects did not exhibit the proper degree of objectivity, is still of interest since it represents the first attempt to draw a dynamic scale of seismic intensity (41).

The G. Mercalli Scale I of 1883 (56) and the G. Mercalli Scale II of 1897 (also known as the Mercalli-Taramelli scale of 1888) (54, 55, 56, 57). A new variation of a seismic scale was proposed in 1897 by G. Mercalli (1850-1914). Even earlier, in 1883, G. Mercalli had attempted to modify the Rossi scale, and, after listing all tremors according to their intensity into 6 grades, used the scale obtained in this manner in describing the Italian earthquakes listed in his catalog (56). However, later in 1888, together with T. Taramelli, and once more in 1897, G. Mercalli again made use of the Rossi-Forel scale, and believed that it was advisable to retain a 10-division scale (54, 57). At the same time, he again modified somewhat the relationship of the divisions, particularly in the area of strong tremors, which were not illustrated in sufficient detail on the Rossi-Forel scale. The proposal made by G. Mercalli was adopted by the Central Meteorological and Geodynamic Service in Rome, and his scale was used during seismic studies in Italy and in certain other countries (55).

The Forel-Mercalli Scale I of 1904 and the Mercalli-Cancani Scale of 1904 (also known as the Forel-Mercalli scale II of 1904, and as the A. Cancani scale of 1904 (19, 82). Several years later, A. Cancani (1856-1904), having found that the new scale of G. Mercalli differs considerably from the Rossi-Forel scale of 1883 and is very similar to the original scale proposed by F. Forel in 1881, proposed, in his report presented at the 2d International Seismic Conference in Strasbourg in 1903, a new name for the Mercalli scale, namely that it should be designated as the "Forel-Mercalli scale" (we designate it as the Forel-Mercalli scale I). Mercalli himself agreed with this new designation. The scale remained a 10-division scale, and is cited in this form, for example, in A. Sieberg's monograph (84, p. 358).

At the same time as he made the above proposal, A. Cancani also found that it would be expedient to expand the scale even more by subdividing the high value divisions, and, in agreement with both Forel and Mercalli, added 2 new divisions to the scale. In addition, he proposed to assign to each division a definite magnitude of seismic acceleration, varying in general within a range of 0-10,000 mm/sec^2. A. Cancani called his division scale an empirical scale, and the acceleration table -- an absolute scale. (19, 35)

In later years, the 12-division scale drawn up in this manner, which became widely used, was known as the Mercalli-Cancani scale, or simply as the Cancani scale.

The Mercalli-Cancani Scale, processed by A. Sieberg, of 1912 (6, 86). Finally, already in 1911, A. Sieberg, an associate of the Central Seismological Bureau in Strasbourg, in collaboration with G. Mercalli, subjected the Mercalli-Cancani scale to a careful analysis, and, on the basis of data obtained during a practical study of a number of earth-quakes and also after studying an extensive literature, modified some-what and supplemented the description of the aftereffects of underground tremors of various intensity, particularly in connection with high divi-sions, retaining, however, the same old 12 divisions and their mutual relationships (85, 86). In this manner, "a detailed scale for determin-ing the intensity of earthquakes, revised by A. Sieberg on the basis of the Mercalli-Cancani scale" (6) was obtained. This particular scale was widely used, and for a long period of time has been utilized and is still being utilized during the study of earthquakes in many countries. In 1917, according to the decision reached by the International Seismo-logical Association, the Mercalli-Cancani-Sieberg scale was adopted as an "international" scale (7).

Such is the rather confusing historical background of the forma-tion of the most widely used, in the recent past, Mercalli-Cancani-Sieberg seismic scale (see Appendix 2).

3. General List of Seismic Scales

Simultaneously with the development of the "international" scale, different modifications of seismic scales were proposed by various authors in different countries.

We shall not examine all these proposals. Information on many of these scales can be found, as was already mentioned, in the monograph published by F. Montessus de Ballore (61), and in articles published by C. Davison (26, 27, 28), V. A. Bykhovskiy (1) and S. P. Lee (44).

We shall merely present here a list of seismic scales (Table 1) which was compiled from the above-mentioned studies of C. Davison and F. Montessus de Ballore (with certain corrections), and also from original sources.

Table 1

List of Seismic Scales

No.	Author	Bibliography	Year	Number of Divisions
1	J. Gastaldi	/85/	1564	-
2	De Poardi	/70/	1627	4
3	D. Pignatoro, Sarconi	/89/	1783	5
4	D. Brooks	/20/	1811	6
5	P. Egen	/30/	1828	6
6	P. Macfarlan	/58/	1839	10
7	A. Peterman	/90/	1856	5

Table 1 (contd)

No.	Author	Bibliography	Year	Number of Divisions
8	R. Mallet (I)	/47/	1858	3
9	R. Mallet (II)	/48/	1862	5
10	R. Williamson	/94/	1870	6
11	M. Rossi	/80,81/	1874	10
12	E. Naumann	/62/	1878	9
13	F. Forel	/32,79/	1881	10
14	A. Heim, V. Forster	/40,45,87/	1882	10
15	M. Rossi, F. Forel	/31,79/	1883	10
16	G. Mercalli (I)	/56/	1883	6
17	G. Johnston-Lewis	/42/	1885	3
18	D. Powell	/52,53/	1886	5
19	C. Rockwood	/78/	1886	6
20	E. Holden	/41/	1888	9
21	H. Masato	/74/	1892	4
22	M. Baratta (I)	/13/	1892	7
23	A. Ricco	/76/	1893	6
24	C. Bassani	/15,16/	1895	16
25	M. Maso	/50/	1895	6
26	F. Suess	/87/	1896	10
27	G. Mercalli (II)	/54,55/	1897	10*
28	R. Oldham (I)	/25/	1897	6
29	R. Oldham (II)	/64/	1899	6
30	S. Sekiya	/68,83/	1899	3
31	Japanese school	/69/	1900	4
32	F. Omori	/66,67/	1900	7
33	C. Davison	/24,28/	1900	9
34	F. Forel, G. Mercalli(I)	/19,82/	1904	10
35	G. Mercalli, A. Cancani	/19/	1904	12**
36	Japanese school	/25/	1906	5
37	H. Wood	/28,95/	1906	5
38	W. Cornish	/23/	1908	11
39	M. Hall	/38/	1909	6
40	M. Baratta (II)	/14/	1910	10
41	J. Milne	/17,59/	1911	3
42	G. Mercalli, A. Cancani, A. Sieberg	/6,86/	1912	12
43	A. McAdie	/51/	1915	10
44	H. Reid, S. Taber	/72/	1919	10
45	F. Omori (II)	/65/	1920	6
46	Japanese school IMOJ	/25,43/	1920	6
47	W. Wong	/91/	1923	11
48	H. Wood, E. Naumann	/18,63/	1931	12

Table 1 (contd)

No.	Author	Bibliography	Year	Number of Divisions
49	J. Ramirez	/71/	1933	3
50	OST-VKS 4537	/10/	1933	12
51	Geophysical Institute of the Academy of Sciences USSR (GEOFIAN) (S. V. Medvedev)	/5/	1953	12
52	GOST 6249-52	/11/	1953	4
53	Academy of Sciences of the Chinese Peoples' Republic	-	1956	12

* Also known as the Mercalli-Taramelli scale of 1888 (57).
** Also known as the Forel-Mercalli scale II of 1904, and as the Cancani scale of 1904.

4. On Seismic Scales Used in Russia and in the USSR

In the studies conducted by the Russian scientists I. V. Mushketov, V. N. Veber, K. I. Bogdanovich and others, the 10-division Rossi-Forel scale was most frequently used. During the study of the Shemakhin and Andizhan earthquakes in 1902, V. N. Veber, M. M. Bronnikov and A. A. Faas worked out, as a supplement to the Rossi-Forel scale, a 7-division scale which corresponded to the 3 higher divisions of the Rossi-Forel scale. We shall not describe this scale here, since it was no longer used during later years.

Since 1930, Soviet seismologists have adopted the 12-division Mercalli-Cancani-Sieberg scale (6). However, the latter does not take into account the conditions prevailing in seismic areas of the USSR, and for this reason cannot be used in a number of cases. Through the efforts of the former Seismological Institute of the Academy of Sciences USSR, this scale was somewhat modified, and in this revised form was approved on 28 March 1931 by the Gosplan USSR as a compulsory scale for use during seismic studies and construction planning work under the conditions present in the USSR. Later, this scale was incorporated into an All-Union standard, and was adopted for compulsory use, starting in 1933, over the entire area of the USSR (OST-VKS 4537 scale (10)) /Note: OST-VKS stands for: _All-Union Standard issued by the All-Union Standardization Committee/.

In the OST-VKS 4537 scale, containing 12 divisions, a corresponding magnitude of seismic acceleration was assigned to each division; this characterizes to a certain extent, although not fully, the intensity of a tremor. For this reason, this gave a false impression of the accuracy and strict physical meaning of the intensity division concept, which did

not correspond to reality. In addition, the various symptoms and factors reflecting the intensity of a tremor (such as destruction of buildings, distortions of the soil, impressions of observers, etc.) were mixed in this scale, and did not give an overall and consecutive picture of the increasing effect produced by an earthquake during its progress from low intensity divisions to high divisions.

On the basis of these considerations, it was deemed necessary at the former Geophysical Institute of the Academy of Sciences USSR to work out a new modification of a seismic scale. This work was done by S. V. Medvedev, who proposed that the intensity of an earthquake should be evaluated on the basis of the magnitude x_o, which is the maximum relative displacement (in millimeters) of a spherical elastic seismometer pendulum. Simultaneously, the design of a pendulum was worked out and experimental samples of the instrument were built. The pendulum has a natural oscillation period $T = 0.25$ sec, and the logarithmic decrement of the damping of oscillations is $\lambda = 0.50$. On the basis of these data, S. V. Medvedev developed a new seismic scale (5), which gave, within a range of 4 to 11 divisions, information on the magnitude x_o, varying from 0.5 to 32.0 mm. In addition, the symptoms produced by the external effect of an earthquake were systematically divided by S. V. Medvedev into 3 groups: 1. Damage inflicted to buildings and structures; 2. Residual effects observed in ground layers, and changes in the condition of subsurface (ground) and surface waters; 3. Other symptoms. The scale consists, as formerly, of 12 divisions (see Appendix 3).

This particular scale, with a range of 6 to 9 divisions, has been adopted by the State Committee for Construction Matters under the Council of Ministers USSR as a State All-Union standard GOST 6249-52 (11) instead of the former scale given in OST-VKS 4537. The scale specified in GOST 6249-52 went into effect on 1 January 1953.

5. Difficulties Encountered During the Correlation of Scales

A comparative analysis of earthquakes, and specifically of isoseism charts, is made considerably more complicated as a result of the presence of such a large number of different scales. It would appear to be useful to effect a comparison of all seismic scales, and thus to achieve a possible correlation of these scales.

The scales listed above are based in most cases on a visual characteristic (description) of the aftereffects produced by an earthquake. For this reason, one should not expect a high degree of accuracy from studies involving a determination of the intensity of underground tremors and the plotting of isoseisms. Contradictions may arise as a result of a different interpretation of a given factor, depending upon local conditions which are difficult to take into account, etc. It is even more difficult, therefore, to devise a satisfactory system for the mutual correlation of scales. This fact, however, does not diminish the practical

importance of such an attempt. On the contrary, it is all the more important to work out some kind of single correlation scheme, which would make it possible to effect a very rough comparison of earthquakes in regard to their external effects.

In order to illustrate the difficulties which are encountered in attempting to correlate seismic scales, we shall mention one example. As was noted above, G. Mercalli, in 1897, proposed his modified 10-division seismic scale (54), which represented a somewhat modified, also 10-division, Rossi-Forel scale (see Table 2, column 1). In 1900, C. Davison (28) gave a conversion of the Mercalli scale into the Rossi-Forel scale (Table 2, column 3). G. Mercalli (55, p. 191) did not agree with the opinion expressed by C. Davison, and soon published his own conversion table (Table 2, column 4). In 1913, a study of G. Martinelli (49, p. 3) was published, in which the author proposed a third variation of the conversion, different from the two previous ones (Table 2, column 5). In 1916, the study of E. Tams (88, p. 317) was published, in 1923, the study of A. Sieberg (85, pp. 100-101), and in 1932, the study of J. Freeman (33, p. 76). In these studies, a number of new and different variations for converting one scale into another are given (Table 2, columns 6, 7, 8).

In the same way, there is no uniformity in converting the indices of the 12-division international scale (the Mercalli-Cancani-Sieberg scale) of 1912 (Table 2, column 2) into the 10-division Rossi-Forel scale. The usual conversion table, proposed already by G. Mercalli (55) and A. Cancani (19) and adopted later by us as the basic table, is shown in column 9 of Table 2. However, for example, in the monograph published by V. A. Bykhovskiy and V. O. Tsshokher (2, p. 24), an entirely different variation of the conversion is listed (Table 2, column 10). The following overall picture is obtained (Table 2).

Similar difficulties are encountered when the magnitude of maximum seismic acceleration is examined. This problem was examined in a considerable number of studies, such as those of E. Holden in 1888 (41), F. Omori in 1900 (67), A. Cancani in 1904 (19), G. Wood in 1908 (95), A. LoSurdo in 1910 (46), M. McAdie in 1915 (51), E. Tams in 1916 (88), N. N. Karlov in 1940 (4), A. Holms in 1949 (9), etc.

Table 2

Discrepancies In Methods for Correlating the Seismic Scales of Mercalli 1897 (10 Divisions), Mercalli-Cancani-Sieberg 1912 (12 Divisions) and Rossi-Forel 1883 (10 Divisions), According to Data Obtained by Various Researchers

Mercalli Scale 1897 (54)	Mercalli Cancani-Sieberg Scale 1912(86)	Corresponding Marks of the Rossi-Forel Scale 1883 — Researchers							
		C. Davison 1900(28)	G. Mercalli 1902(55)	G. Martinelli 1913(49)	E. Tams 1916 (88)	A. Sieberg 1923(85)	J. Freeman 1932 (33)	A. Cancani 1904(19)	V.A. Bykhovski, V.O. Tsshckhe 1937 (2)
1	2	3	4	5	6	7	8	9	10
—	1	1	1	1	1	1	1-2	1	1
1	2	2-	2	2	2	2	3	2	2
2	3	3	3	3	3	3	4	3	3
3	4	4-5	4	3-4	4	4	4-5	4-5	4
4	5	5-6	5-6	6	5-6	5-6	5-6	6	5
5	6	7	7	7	7	7	7	7	6
6	7	8	8	8	8	8	8	8	7
7	8	8-9	9	9	9	9	9	9	8
8	9	10	10	10	10	10	10	10	9
9	10	—	—	—	—	—	—	—	10
10	11	—	—	—	—	—	—	—	—
—	12	—	—	—	—	—	—	—	—

6. Attempts to Establish Absolute Criteria of Earthquake Intensity

In view of the great variety of conditions under which earthquakes can manifest themselves, it is clear that a strict accord between visual observations and an evaluation of the intensity of underground tremors cannot be achieved, at least until the time when it will be possible to devise a sufficiently convenient and physically substantiated system for evaluating seismic intensity. Such attempts, i.e. attempts to establish absolute scales, have been made many times.

Thus, B. B. Golitsyn in 1911 (34), on the basis of experimental data derived from the tilting (overturning) of parallelepipeds, developed a 10-division "dynamic scale," in which the magnitude of maximum acceleration varied from 20 to 200 cm/sec^2 with a height of parallelepipeds ranging from 82.9 to 7.9 cm. J. Milne and F. Omori (60, 69) attempted to solve this problem in a similar manner.

In 1931, G. Agamennone and A. Sauve developed a scale, which was based on measurements of displacements (from 0.07 to 0.70 cm) and accelerations (from 9 to 92 cm/sec^2) with the aid of an instrument proposed by them (12).

In 1933, H. Wood, in a brief notice, gave a review of earlier empirical scales, and also attempted to clarify the concept of the intensity of underground tremors. He suggested that the intensity be defined as the product of acceleration and the oscillation frequency of soil particles (93).

In 1935, C. Richter (77), and later B. Gutenberg (37), as a result of a careful analysis of maximum amplitudes recorded by stations located at various epicentral distances, developed an "absolute" scale M ("magnitude scale") with intensity indices ranging from 0 to 8.5. In this connection, it was found that tremors on the surface of the ground which can only be recorded by instruments correspond to an intensity 0 in the focus of the earthquake; when M = 1.5, tremors can be felt by people; when M = 3, the tremors are felt over a considerable area; when M = 4.5, the tremors are capable of inflicting light damage in the epicenter zone; when M = 6, destruction can be observed over a certain limited area; when M = 7.5, this corresponds to the lower limit of the most violent earthquakes. C. Richter uses the following figures to describe the intensity in the focus of certain earthquakes (the intensity division ratings in the epicenter according to the GOST 6249-52 scale are given in brackets): in Santa Monica Bay, 1930, M = 5.2 (7 divisions); in Long Beach, 1933, M = 6.2 (8 divisions); in the state of Utah, 1934, M = 7.0 (9 divisions). Later, B. Gutenberg and C. Richter studied the problem concerning the relation between the force of tremors, the intensity, energy and accelerations (37), and were able to successfully use their "absolute scale" during an analysis of instrumental data on world earthquakes (3).

A similar study was conducted by R. Hayes, who established the manner in which the indices of the "absolute" scale correspond to the divisions of the Rossi-Forel scale, namely: M = 4.0 corresponds to 4 divisions of the Rossi-Forel scale; M = 5.0 corresponds to 6-7 divisions on the same scale; and M = 6.0 corresponds to 8 divisions on this scale (39).

Attempts have been made to express intensity divisions (bally) with the aid of fractions of acceleration of the gravity force, which, apparently, represents a modification of the scale of accelerations acquired by soil particles under the action of seismic waves. The use of such figures, for example, was suggested by P. N. Tverskoy (8). The numerous attempts to express the intensity of underground tremors by means of the concept of accelerations of soil particles (in mm/sec^2) have already been mentioned.

7. Correlation of Seismic Scales

In view of the great complexity of the problem concerned with the establishment of strict quantitative criteria of the intensity of underground tremors, the elementary concept of a seismic intensity division as an arbitrary unit of the intensity of an earthquake retains its significance and proves to be useful during macroseismic studies. This results in the necessity of establishing at least an approximate, but uniform, system of transition from one seismic scale to another.

With this purpose in mind, we have attempted to set up a table for the correlation of seismic scales (see Table 4). Some of the scales used in this table were briefly described at the beginning of this article, namely those scales which are associated in one way or another with the Rossi-Forel, Mercalli-Cancani-Sieberg and GEOFIAN (S. V. Medvedev) scales. As a basis for the transition from the 10-division scale of G. Mercalli of 1897 and the 12-division scale of Mercalli-Cancani of 1904 to the 10-division Rossi-Forel scale of 1883, we used the studies conducted by G. Mercalli in 1902 (55) and A. Cancani in 1904 (19), which contain proposals most closely related to the conclusions derived from a direct comparison of these scales, and to what has been accepted by most researchers (26, 36, 55, 60 and many other references) (Table 3).

Table 3

Comparison of the Most Important Foreign Seismic Scales

Scale	Divisions											
Rossi-Forel 1883	1	2	3	4-5	6	7	8	9	10	–	–	–
Mercalli 1897		1	2	3	4	5	6	7	8	9	10	–	–
Mercalli-Cancani 1904	1	2	3	4	5	6	7	8	9	10	11	12

In regard to all other transitions, one might state that they are effected either by directly comparing the indices of corresponding scales, or by making use of considerations presented in various studies by the actual authors of the scales or by persons who have made a special study of this problem (26, 27, 29, 33, 44, 85, etc.). In particular, we have used an interesting table giving a comparison of 15 scales, published in the monograph of F. Montessus de Ballore (61, p. 61).

The R. Egen 1828, M. Rossi 1874 and M. Baratta-I 1892 scales are referred to the Rossi-Forel scale, and then to the GEOFIAN scale, in accordance with the table just mentioned above (61). However, in comparing these scales, a discrepancy was noted. Thus, one of these scales, namely the R. Egen 1828 scale, is converted, according to data published by F. Montessus de Ballore, into the Rossi-Forel scale in a different manner than was done somewhat later by A. Sieberg (85, p. 100). In view of the absence of specific indications on the part of the actual authors of the scales, and since the macroseismic indices were not sufficiently clear, we stuck to the table given by F. Montessus de Ballore.

A comparison of the original F. Forel 1881 scale with the consolidated Rossi-Forel scale of 1883 was effected in accordance with the indications given by the author himself, F. Forel (31, p. 149).

The Heim-Forster 1882 scale was referred to the Forel scale, and then to the remaining scales, in accordance with the table given by F. Suess (87, p. 453).

A system for effecting the correlation of the Rossi-Forel scales, and then of the R. Malleta-II, M. Maso, C. Davison and M. Baratta (II) scales, was devised at one time by C. Davison (28), and we borrowed his data (with certain corrections, in view of a different interpretation of the Rossi-Forel scale, see Tables 2 and 3). The same data, referring to Davison's 9-division scale ("simplified British scale"), were later confirmed by Davison in 1915 in an article describing earthquakes occurring in Great Britain (24, p. 360).

A comparison of C. Rockwood's scale of 1886 with Rossi-Forel's scale, and then successively with the GEOFIAN scale, was performed according to the directives given by C. Rockwood himself, given in his latest study devoted to earthquakes occurring in California (29, p. 145; 78, p. 7).

Certain data referring to the scales of R. Mallet, J. Milne and E. Holden were obtained from T. Mendenhall's article (52).

C. Bassani's scale of 1895 was compared with the Rossi-Forel scale according to the data given by F. Montessus de Ballore (61, p. 54).

R. Oldham's scale I of 1897 was reduced to the divisions given in the Rossi-Forel scale according to the data published by C. Davison (25, p. 140). The conversion of R. Oldham's scale II of 1899 into the Rossi-Forel scale was performed in accordance with the directives given by R. Oldham himself (64, p. 43).

A rather confusing system of seismic scales was used in Japan. In 1892, a scale developed by H. Masato, consisting of 3 divisions, made its appearance. This scale was used by S. Sekya during the compilation of his catalog listing the earthquakes which occurred in Japan during the period 416 to 1867 (83). We have compared this scale with the Rossi-Forel scale in accordance with the most recent data published by J. Freeman (33, p. 81). While analyzing S. Sekya's data, F. Omori found that it was expedient to subdivide division 3 into 2 divisions (68, p. 389), and in this revised form, the new 4-division scale was later recommended for use by the Central Meteorological Observatory in Tokyo (1900). We have compared this scale with the Rossi-Forel scale in accordance with the directives given by F. Omori, who conducted a special study of this problem (69, p. 138), and also by J. Freeman, who arrived at the same conclusions (33, p. 81). Finally, at the same time, F. Omori published the results of his observations on the accelerations of soil particles during the catastrophic earthquake of 1891 in Mino-Ovari, and on this basis, recommended the use of a new 7-division scale intended for the study of strong earthquakes, which he himself correlated with the Rossi-Forel scale. We made use of these studies conducted by F. Omori (67, 69); the same system of correlation was also adopted by F. Montessus de Ballore (61, p. 55); for the first 3 divisions, G. Wood proposes a somewhat different system, which, however, differs from our system in an absolutely insignificant way (92, see also /33/, p. 362). For information on the 7-division scale of Omori, and also on the scales of C. Davison, A. Cancani and a number of other authors, see also the articles published by G. Wood (96) and E. Tams (88).

Information on the Japanese scale of 1906 was obtained from the studies of A. Sieberg (22) and E. Shey and R. Lice (22). Finally, the Japanese scale IMOJ (Imperial Meteorological Observatory of Japan) was referred to the Rossi-Forel scale in accordance with the data published by S. Kunitomi (43, p. 83) and also by C. Davison (25, p. 253).

The scale developed by V. Cornish in 1908 was correlated with the Rossi-Forel scale according to directives given by V. Cornish himself, who believed that the numeration of divisions developed by him (and utilized during the study of the earthquake which occurred in Jamaica on 9 December 1907) is completely in agreement with the Rossi-Forel scale, except for the highest division, which V. Cornish subdivided into 2 divisions, namely divisions 10 and 11 (23, p. 270).

G. Wood's scale of 1906 (95), drawn up for use in connection with strong earthquakes and used during the study of the California earthquake of 18 April 1906 (San Francisco Scale), was referred to the divisions given in the Rossi-Forel scale in accordance with indications given by the author himself (33, p. 362; 92), although it must be stated that G. Wood interpreted the meaning of the divisions in Rossi-Forel's scale in a somewhat arbitrary manner.

The 3-division scale of J. Milne of 1911, which J. Milne used in compiling his well-known world catalog of destructive earthquakes which had occurred from the beginning of our era until the end of the 19th century, was correlated with the Rossi-Forel scale in accordance with J. Milne's data on the magnitudes of accelerations adopted by him: 1 division corresponding to an acceleration of 100 mm/sec^2, 2 divisions corresponding to an acceleration of 1,500 mm/sec^2, and 3 divisions corresponding to an acceleration of over 3,000 mm/sec^2 (59, p. 5-6).

The scale developed by one of the oldest Chinese seismologists, W. H. Wong, in 1923, was drawn up by him in the following manner: the scale was based on the Rossi-Forel scale, but an additional 11th division was added to describe very strong earthquakes (91, p. 11), and this was reflected in our table. Recently, the Geophysical Institute of the Academy of Sciences of the Chinese People's Republic has developed a scale, which takes into account the peculiarities of Chinese construction methods, the quality of building materials used and the properties of ground layers, etc.; this scale is correlated with the GEOFIAN scale of 1953.

Finally, the J. Ramirez scale is correlated with the Rossi-Forel scale in accordance with indications given by the author himself (71, p. 13).

As a general result of this work, a correlation table was obtained, which contains 44 scales (Table 4). This table is compiled in such a way, that all scales are referred to the GEOFIAN scale of 1953 (11). Obviously, such a system only provides an approximate evaluation when the various scales are compared with each other, and does not make any claims for accuracy. This table can be considered as sufficiently accurate only in case of such scales as the Rossi-Forel scale of 1883, the Mercalli-Cancani-Sieberg scale of 1912, and the GEOFIAN scale of 1953.

Appendix 1

Rossi-Forel Scale of Seismic Intensity of 1883 (31, 79)

Division I. Microseismic tremor, recorded only with the aid of a seismograph or with seismographs of specific design, but not with all types of seismographs. The tremor is felt by an experienced observer.

Division II. Exceedingly weak tremor, recorded by many seismographs of different design. Tremor is felt by a small number of people at rest.

Division III. Very weak tremor, perceived by many people at rest. The tremor is sufficiently strong to allow an observation of the direction and an evaluation of the duration of the effect.

Division IV. Weak tremor, perceived by people in motion. Shifting of mobile objects, doors and windows. Cracks in ceilings.

Division V. Tremor of moderate intensity, usually perceived by all people. Shifting of furniture, beds, etc. Ringing of swinging small bells.

Division VI. A noticeable strong tremor; general awakening of all sleeping people. General ringing of house bells, swinging of chandeliers, stopping of pendulum clocks. Noticeable agitation of trees and shrubs. A number of frightened people leave their dwellings.

Division VII. Strong tremor; falling of mobile objects. Plastering on ceilings and walls falls off. Ringing of church bells. General panic. No serious damage to buildings.

Division VIII. Very strong tremor; falling of smokestacks. Cracks formed in the walls of buildings.

Division IX. Exceedingly strong tremor; partial or general disintegration of certain buildings.

Division X. Tremor of exceptionally strong intensity; enormous catastrophy. Buildings are converted into ruins. Destruction of the ground, cracks in the ground. Falling of rocks in mountain areas.

Appendix 2

Detailed Scale for Determining the Intensity of Earthquakes, Processed by A. Sieberg on the Basis of the Mercalli-Cancani Scale of 1912 (6).

Division I. Not noticeable (maximum acceleration (2.5 mm/sec^2). Recorded only with the aid of instruments.

Division II. Very weak ($2.6-5.0 \text{ mm/sec}^2$). Perceived by a small number of nervous or very sensitive people, present in a state of complete rest, particularly in the upper floors of dwellings.

Division III. Weak ($6-10 \text{ mm/sec}^2$). Even in a densely populated locality, the tremor is perceived only by a small fraction of the population, in the form of a shaking, similar to the impression made by a horse carriage which has rapidly passed by. Sometimes, it is possible to determine the duration and the direction of the movement. Many people are able to find out that the vibration was caused by an earthquake only after subsequent conversations.

Division IV. Moderate ($11-25 \text{ mm/sec}^2$). In the open, is perceived by few people. Inside buildings, is perceived by many people, but not by everyone, as a result of a tremor or slight oscillation of household articles; as a result of this tremor, tightly packed glassware and china emit a faint ringing sound, similar to the one caused by the passage of a truck over a rough paved road. Ringing of window panes, squeaking of doors, rafters and floors. Cracks in the ceilings. Slight vibration of liquids in open vessels. Such an earthquake causes practically no anxiety among people, with the exception of persons who have become nervous or frightened as a result of previous earthquakes. Individual cases of awakening among sleeping people do occur.

Division V. Rather strong (26-50 mm/sec^2). In the street, or generally in the open, the tremor is perceived by a large number of people, even by people fully engaged in daytime work. Inside buildings, it is perceived by everyone as a result of a general shaking of buildings. The impression made by this tremor is similar to the one produced by the falling of a heavy object (bag, furniture piece) in the house. Shaking of chairs and beds, together with people occupying these pieces of furniture, similar to rocking on the sea. Swinging of plants and weaker branches on shrubs and trees, as during a moderate wind. Oscillating movement of freely hanging objects, such as draperies, icon lamps, hanging lamps and not too heavy chandeliers. A ringing sound can be heard. Clock pendulums either stop or swing along a wide arc, depending upon whether the direction of the tremor is perpendicular to the swinging course of the pendulum or runs in the same direction, as a result of which the stopped clock and pendulum may again be set in motion. Ringing of watch springs. Electric lights start blinking or go out as a result of wire connection. Pictures are slammed against the wall or shift their position. Spilling of a portion of liquids in filled open containers. Possible falling of trinkets, standing frames and objects leaning against the walls; lighter objects may shift their position. Squeaking of furniture. Doors and window shutters are opened or slammed shut. Cracks in window panes. Awakening of sleeping people. Some residents run out into the street.

Division VI. Strong earthquake (51-100 mm/sec^2). Perceived by all people and causing fright; very many people run out into the street and have a feeling of being doomed. Strong agitation of liquids. Falling of pictures from walls and of books from bookcases, except from those bookcases standing against walls oriented in the same direction as the tremor. Glassware and china is broken. Rather stable household items, even furniture, are displaced or overturned. Ringing of small bells in chapels and churches. Chiming of tower clocks. Fine cracks appear in the plastering of certain houses, even those having a solid structure. In houses of poor construction, more extensive damage is observed, although this damage is still not of a dangerous character.

Division VII. Very strong earthquake (101-250 mm/sec^2). Considerable damage to household objects as a result of the falling and breaking of even large objects. Ringing of even large bells. Symptoms of agitation are observed in rivers, ponds and lakes, and their water becomes turbid due to mud formation. Individual cases of landslides on sandy and gravel banks are observed. Change in the water level of wells. Moderate damage in houses of even a solid European construction: light cracks in walls, substantial fragments of plastering, plastic decorations and bricks are split off, roofing tiles are loosened and start falling; damage to smokestacks caused by cracks, falling of tiles and bricks. Defective stacks crumble on roofs and damage them. Loose or poorly attached ornamental structures fall from towers and high buildings. In frame buildings, damage to plastering and frame

filling material is even greater. Severe damage to poorly built or old buildings. The first type of buildings includes, for example, hollow brick structures widely used in Central America, and also small stone houses and mud huts found in certain Northern seismic regions, such as for example in Iceland, as well as board hedges, sheds, old stone enclosures, particularly those which are made out of separate stones without the use of cement, huts, mosque minarets, etc. Rural structures may suffer extensive damage. On the other hand, special antiseismic structures, such as the majority of Japanese stone and even wooden houses, as well as wooden and woven structures used in most tropical seismic regions, remain undamaged.

Division VIII. Destructive earthquake (251-500 mm/sec^2). Whole tree trunks, particularly palm tree trunks, are rapidly set into a swaying motion or even break up. Even heavy household objects are displaced over a great distance and are partly overturned. Statues, monuments and other similar structures located near the surface of the ground, i.e. in churches, cemeteries, boulevards, turn about on their pedestals or are overturned. Strong stone fences disintegrate and crumble. The bulk of the filling materials in frame buildings falls out. Standard wooden houses, such as those found in many places in North America, are crushed or overturned. European-type dwellings, even those with a solid structure, suffer severe damage as a result of large cracks in walls, and some buildings are partially destroyed. Most smokestacks crumble. The crumbling of church towers and factory smokestacks inflicts a greater amount of damage to adjacent houses than does the earthquake itself. Particularly well-built factory smokestacks break off only in their upper section and suffer a shift.

Antiseismic (Japanese, etc.) brick structures already suffer some damage, such as cracks, splitting off of plastering, etc. (see division 7 in case of European structures). Similar wooden houses suffer cracks at the seams. Rotten poles in Malayan pole structures break down. Light cracks are observed on steep hills and on humid ground. In some spots, a small amount of water, mixed with sand and mud, seeps out of the ground.

Division IX. Devastating earthquake (501-1,000 mm/sec^2). Severe damage to stone houses of solid European construction, many of which become unsuitable for living purposes, and some crumble down completely or to a great extent. Frame buildings are displaced from their stone foundations, cave in, and frame braces break down, causing even greater damage. Antiseismic stone buildings suffer considerable damage. Plastering on wooden houses forms cracks and fissures. Old wooden houses become slightly distorted.

Division X. Annihilating earthquake (1,001-2,500 mm/sec^2). The majority of stone and frame buildings are destroyed together with their foundations, even strong brick walls form dangerous cracks. The rate of damage in European structures is higher than that of antiseismic structures. Severe damage inflicted even to well-built wooden houses

and bridges, some of which are even destroyed. More or less extensive damage to embankments and dams. Slight warping of railroad tracks. Pipes laid in the ground (gas, water and sewage pipes) break down or become clogged. Stone and asphalt pavement form cracks and wave-like folds caused by protrusion. Loose, and particularly, moist soil forms cracks measuring up to several decimeters in width. In addition to landslides of loose soil from rocky slopes, partial rock slides are also observed. A caving-in of considerable sectors is observed along river banks and on steep sea shores, and sliding shifts of sand and mud formations are observed on sloping shores, which occasionally results in a considerable change of the relief. Frequent change of the water level in wells. Spilling of water ashore from rivers, canals, lakes, etc.

Division XI. Catastrophy (2,501-5,000 mm/sec^2). Practically nothing is left of all types of stone structures. Even strong wooden and flexible woven structures, particularly those located near rifts, may remain partially intact. Among bridge structures, even large and strong bridges are destroyed in view of the crumbling of stone pillars or the warping of metal girders. A smaller amount of damage is sometimes observed in more flexible wooden bridges. Complete break up, frequently even over a considerable distance, of embankments and dams. Strong warping and protrusion of railroad tracks. The nature of the ground is of decisive importance in regard to the nature and extent of damage suffered by means of communication. Underground pipes break down completely and become unsuitable for use. Numerous and extensive changes in ground surface layers, determined by the nature of the soil. Wide cracks are formed especially in loose and moist earth, running in a horizontal and vertical direction. Water seepages, containing admixed sand and mud, are observed, having a great variety of forms characteristic for this particular phenomenon. Numerous landslides and avalanches.

Division XII. Strong Catastrophy ($>$5,000 mm/sec^2). Not a single structure erected by human hands can withstand this type of earthquake. Changes in the soil reach enormous proportions. Even on rocky soil covered with vegetation, fault cracks of considerable displacement magnitude are formed, as well as horizontal dislocations and faults. Numerous rock slides, landslides and shore (bank) crumblings covering a considerable area are observed. Various changes in underground and surface water reservoirs. Appearance of water falls, secondary lakes, deviations in the course of rivers, etc.

Appendix 3

GEOFIAN Seismic Scale (see Note)

Drawn up by S. V. Medvedev in 1953 (5)

(Note: The scale extending from divisions 6 to 9 was adopted as standard GOST 6249-52 (11).

1. The intensity of an earthquake in divisions (intensity rating) is determined by the magnitude x_o, which is the maximum relative displacement of an elastic spherical seismometer pendulum. This pendulum has a natural oscillation period $T = 0.25$ sec, and a logarithmic decrement of attenuation (damping) $\lambda = 0.50$.

Values of x_o, expressed in millimeters, are listed in Table A.

Table A

Division	Type of Earthquake	x_o, mm	Division	Type of Earthquake	x_o, mm
1	Not noticeable	-	7	Very strong	2.1-4.0
2	Very weak	-	8	Destructive	4.1-8.0
3	Weak	-	9	Devastating	8.1-16.0
4	Moderate	< 0.5	10	Annihilating	16.1-32.0
5	Rather strong	0.5-1.0	11	Catastrophy	> 32.0
6	Strong	1.1-2.0	12	Great Catastrophy	-

2. The intensity of an earthquake in points where no seismometers are available is characterized by Table B; in order to determine the degree of damage and destruction inflicted by the earthquake on buildings erected without the necessary antiseismic measures, this table contains the following subdivisions:

I. According to Types of Buildings

Group A - One-story high houses with walls of jagged stone, raw brick, adobe, etc.
Group B - Brick and stone buildings.
Group C - Wooden houses.

II. According to the Extent of Damage

Light damage - Fine cracks in plastering and stoves, crumbling of whitewashing, etc.
Considerable damage - Cracks in plastering and stoves, splitting off of plastering fragments, fine cracks in walls, cracks in partitions, damaged smokestacks, furnaces, etc.

Destruction - Large cracks in walls, breaking up of masonry, crumbling of wall sections, falling cornices and parapets, crumbling of plastering, falling smokestacks, etc.

Collapse - Crumbling of walls, ceilings and roofs in the entire building or of considerable portions of the building; great deformations of walls.

III. According to the Number of Buildings

Most buildings, numerous buildings, individual buildings.

Table B

a. Behavior of buildings and structures

Division 1. No damage
Division 2. "
Division 3. "
Division 4. "
Division 5. Light squeaking of floors and partitions; rattling of window panes, crumbling of whitewashing, movement of open doors and windows. Light damage in individual buildings.

Division 6. Light damage in many buildings. Considerable damage in individual buildings belonging to Groups A and B. In rare cases, when the ground is wet, formation of fine cross-sectional cracks on roads.

Division 7. In most buildings of Group A, considerable damage, and in individual cases, destructive damage. In most buildings of Group B, light damage, and considerable damage in many buildings of this group. In many buildings of Group C, light damage, and in individual buildings, considerable damage. Occasional landslides on steep road embankments, and in individual cases, formation of cross-sectional cracks on roads. In isolated cases, dislocation of pipe joints. Damage in stone fences.

Division 8. In many buildings of Group A, destructive damage, and crumbling of individual buildings. In most buildings of Group B, considerable damage, and destructive damage in individual buildings. In most buildings of Group C, light damage, and considerable damage in many buildings of this group. Small landslides on steep slopes of road depressions and embankments. Individual cases of broken pipe joints. Monuments and statues are shifted or overturned, stone walls crumble.

Division 9. Destruction of many buildings of Group B, and crumbling of individual buildings in this group. In many buildings of Group C, considerable damage, and destruction of individual buildings in this group. In some cases, damage to road embankments. In individual cases,

distortion of railroad tracks. Large number of cracks on roads. Numerous breaks and damage in pipes. Monuments and statues are overturned. A large proportion of stacks and towers is destroyed.

Division 10. Many buildings of Group B crumble down. Many buildings of Group C are destroyed, and individual buildings in this group crumble down. Considerable damage to embankments and dikes. Local distortions of railroad tracks. Breakdown of pipes. Roads exhibit a large number of cracks and deformations. Toppling down of stacks, towers, monuments and fences.

Division 11. General destruction of buildings. Destruction of road embankments over a large area. Pipes and pipe-lines are completely knocked out of commission. Railroad tracks are distorted along their entire length.

Division 12. General destruction of buildings and structures.

b. Residual Phenomena in Ground Layers and Changes in the Normal Conditions of Surface and Ground Water Systems.

Division 1. No disturbances.
  "   2.   "
  "   3.   "
  "   4. Individual cases, formation of cracks in wet ground is possible.

Division 5. In rare cases, fine cracks in moist ground layers. Slight waves in artificial water reservoirs. In individual cases, a change is observed in the discharge rate (flow) of water sources.

Division 6. Cracks up to 1 cm wide in moist ground layers. In mountain regions, isolated cases of landslides and ground crumbling. Small changes in the discharge rate of sources and in the water level in wells.

Division 7. Fine cracks in dry ground. Large number of cracks in wet ground. Individual cases of landslides on river banks. In mountain regions, small landslides and ground crumbling. Mountain avalanches are possible. In individual cases, water in water reservoirs and rivers becomes turbid. Changes take place in the discharge rate of sources and in the level of ground waters. In some cases, new water sources appear or existing sources disappear.

Division 8. Cracks in the ground reach a size of several centimeters. Numerous cracks on mountain slopes in moist ground. Large scale crumbling and landslides, extensive mountain avalanches. The water in water reservoirs becomes turbid. New water sources make their appearance and existing sources disappear. A change in the discharge rate of sources and in the water level of wells is frequently observed.

Division 9. Formation of cracks in the ground up to 10 cm wide. Cracks more than 10 cm wide are formed on river banks and slopes. Large number of fine cracks in the ground. Mountain avalanches, large number

of landslides, crumbling of ground. Small mud eruptions. Large-scale agitation of water in water reservoirs. Frequent appearance of new water sources or disappearance of existing sources.

Division 10. Formation of cracks in the ground up to several decimeters wide, and in individual cases, up to 1 meter wide. Rock slides in mountain regions and on the seashore. Large-scale landslides of sandy and clay formations. Surf formation and spilling of water ashore in water reservoirs and rivers. Formation of new lakes.

Division 11. Formation of numerous cracks on the surface of the ground. Vertical displacements of earth layers (strata). Extensive avalanches and landslides. Loose, water-saturated, deposits creep out of cracks. Extensive changes take place in the condition of sources and water reservoirs, and in the level of ground waters.

Division 12. Large-scale changes in the relief. Enormous avalanches and landslides. Extensive vertical and horizontal faults and dislocations. Extensive changes in the regime of ground and surface waters. Formation of waterfalls, appearance of new lakes, changes in river beds.

c. Other Symptoms

Division 1. The earthquake is not felt. Vibrations of the ground are recorded by means of instruments.

Division 2. The earthquake is felt by individual, very sensitive, people, remaining in a state of complete rest.

Division 3. Attentive observers are able to notice a very slight swaying of hanging lamps, flowers standing in rooms, draperies, open doors, standing motor vehicles. Vibrations are felt by a few people at rest inside buildings.

Division 4. Slight swaying of hanging objects and standing motor vehicles. Slight agitation of liquids in vessels. Weak ringing of tightly packed fragile dishware (china). The earthquake is felt by most people present inside buildings. In rare cases, sleeping persons awake. The earthquake is felt by individual people in the open.

Division 5. Noticeable swaying of hanging objects. In rare cases, the pendulums of wall clocks stop. Liquid sometimes spills out of filled containers. Unsteady dishware and decorations (ornaments), standing on shelves, are overturned. The quake is felt by all people inside buildings and by most people in the open; everybody wakes up. Animals show signs of agitation.

Division 6. Swinging of hanging objects. Occasionally, books fall from shelves, and pictures are displaced. Many pendulums of wall clocks stop. Light furniture shifts from its normal position, dishware falls down. Many people run out of their quarters. People walk in an unsteady manner. Animals run out of their shelters.

Division 7. Strong swaying of hanging lamps. Light furniture is shifted. Books, dishware and vases fall down. All people run out of their quarters, and in some cases jump out of windows. It is difficult to move about without support.

Division 8. A portion of hanging lamps is damaged. Furniture is displaced, and partly overturned. People are hardly able to stand on their feet. Everybody runs out of their quarters.

Division 9. Furniture is overturned and broken. Animals show signs of great agitation.

Division 10. Extensive damage to household articles. Animals run around screaming. Tree branches and old tree trunks are broken.

Division 11. Destruction of property under the debris of buildings.

Division 12. Great catastrophy. A considerable portion of the population perishes under crumbling buildings. Plants and animals perish under avalanches and landslides in mountain regions, and also under tidal waves.

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